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NASA/Air Force Cost Model

NAFCOM

Science Applications International Corporation

Propulsion for Space Transportation of the 21st Century
May 15, 2002

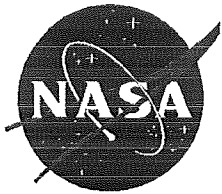
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- ◆ Redesign Summary
- ◆ NAFCOM Features
- ◆ NAFCOM Sample Screens
- ◆ Planned Release and Training



NAFCOM Description



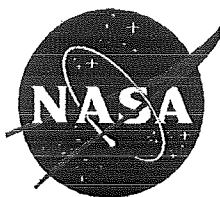
The NASA/Air Force Cost Model (NAFCOM) is a parametric estimating tool for space hardware. It is based on historical NASA and Air Force space projects and is primarily used in the very early phases of a development project. NAFCOM can be used at the subsystem or component levels.



NAFCOM Database

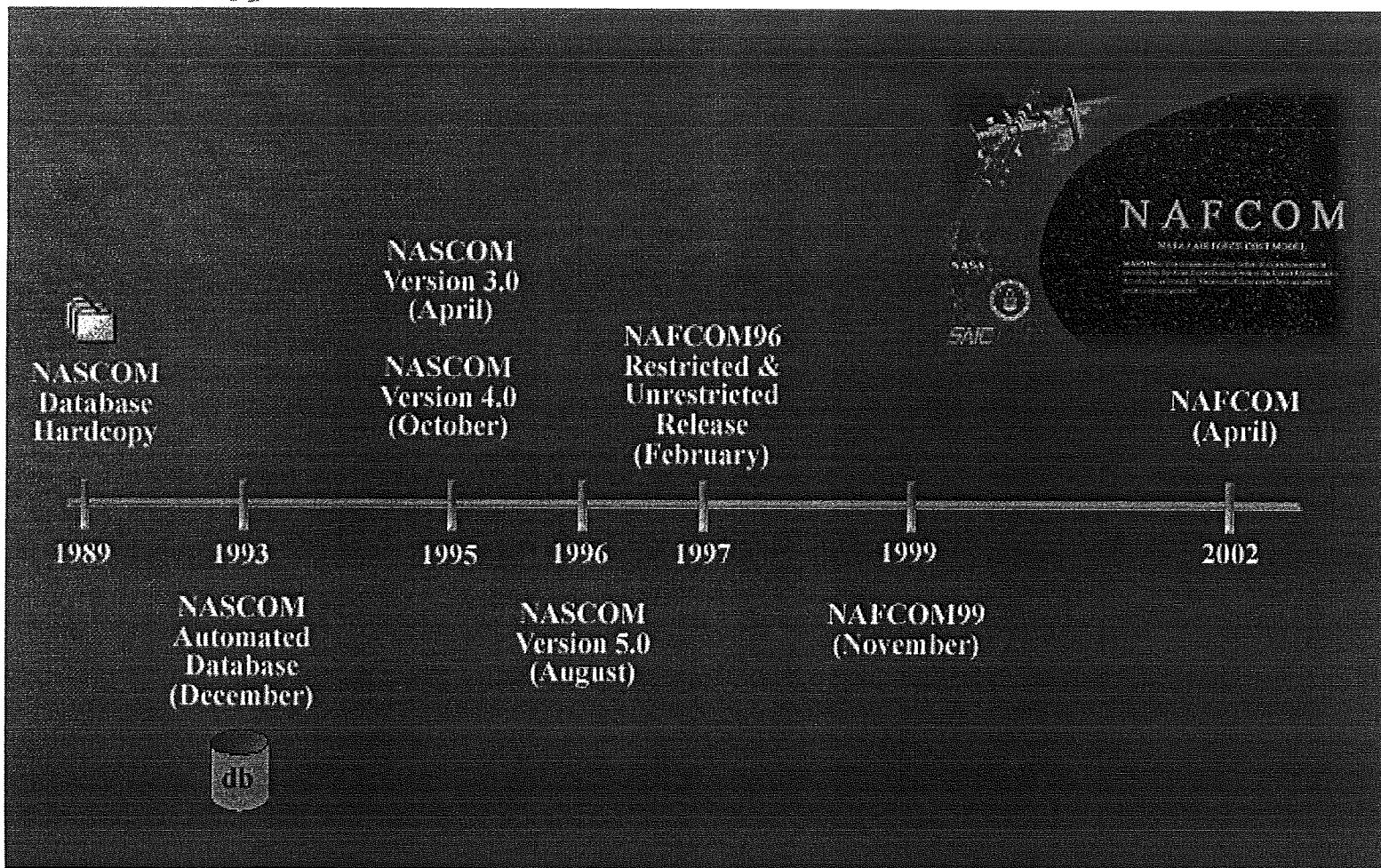


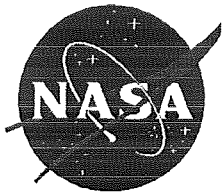
- ◆ NAFCOM is based on spacecraft data from the Resource Data Storage and Retrieval Library (REDSTAR)
- ◆ REDSTAR is NASA's major repository of cost, technical, and programmatic information including over 25,000 documents
 - 540 companies, government agencies, universities, and aerospace societies represented
 - Total program to subcomponent cost data
 - Information on spacecraft bus, attached payloads, engines, launch vehicles, upper stages, scientific instruments, aircraft, DoD, cost models and cost estimating, schedules, ground and launch operations, mission operations, Lessons Learned
- ◆ The normalized database includes 122 missions with:
 - 76 unmanned earth orbiting, 24 unmanned planetary, 11 launch vehicles, 8 manned, 3 engines



NAFCOM Evolution

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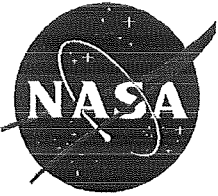




NAFCOM Features



- ◆ Subsystem-level Complexity Generators
- ◆ Process-based Schedule Estimating
- ◆ Time Phasing of Cost
- ◆ Cost Trades
- ◆ Enhanced Engine Estimating
- ◆ Integration into CEC
- ◆ Quick estimate startup with use of template wizard
- ◆ Expert knowledge of database embedded in template selection process



NAFCOM Features



◆ Subsystem Level Complexity Generators

- Application of multiple cost drivers

- ❖ The equations follow the form:

$$\text{Cost} = C * \text{Weight}^W * \text{Inheritance}^X * \text{Technology}^Y * \text{Management}^Z$$

- Data driven, statistically based
- Documents estimating assumptions
- Minimizes the use of subjective inputs
- Repeatable and verifiable
- Nine new complexity generators have been developed including SRM, propulsion (less engines), OMS, TVC, recovery, landing, thermal control, crew accommodations, and ECLS.

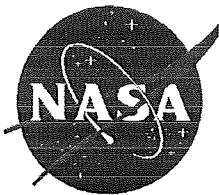


NAFCOM Features



◆ Process-based Schedule Estimating

- SAIC identified the processes for currently defined common subsystems and system integration elements and tied these processes to schedule estimating algorithms
- The methodology considers cost and technical parameters in the calculation of the schedule baselines
- Three levels of schedules are generated:
 - ❖ System level by Stage
 - ❖ Stage level by Subsystem
 - ❖ Subsystem level by Process

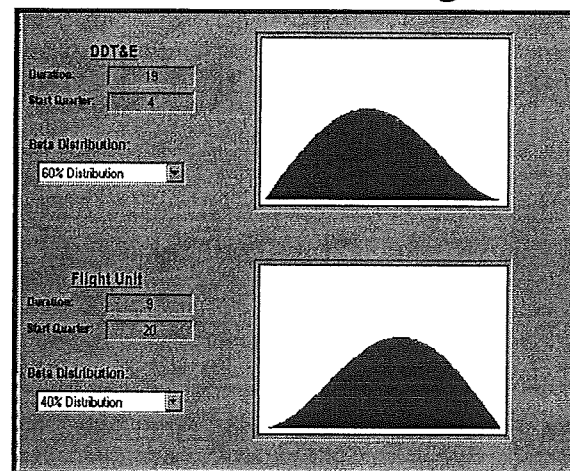


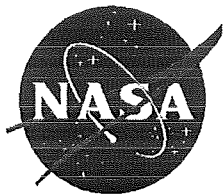
NAFCOM Features



◆ Time Phasing of Cost

- Developed using schedules generated in process-based module
- Cost is spread at the subsystem level
- DDT&E and flight unit cost are shown separately
- User may select either fiscal or calendar years
- Beta distributions can be changed for DDT&E and flight unit





NAFCOM Features

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◆ Cost Trades

- Allows the user to perform “what if” scenarios based on global changes to technical factors:

- ❖ Weight
- ❖ Manufacturing management
- ❖ Engineering management
- ❖ New design
- ❖ System Test Hardware

The screenshot shows a software interface for cost trades. It has four input fields at the top: Weight, Mfg Management, Eng Management, and New Design, each with a '% Change' label. Below these is a 'System Test Hardware' section with 'STH Qty' and '% of Flight Unit' input fields, each with a '% Change' label. At the bottom is a 'Cost Comparison' table.

DOT&E Cost		Flight Unit Cost	
15,762.4	15,762.4	3,888.2	3,888.2
Production Cost		Total Cost	
3,888.2	3,888.2	19,650.7	19,650.7

Buttons at the bottom: Trade, Cancel, Help, OK.

- One, all, or a combination of the factors can be increased or decreased by a percentage to determine the effect these changes have on total cost



NAFCOM Features

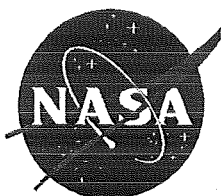


◆ Enhanced Engine Estimating

- Fully integrated versions of a liquid rocket engine model and a combined cycle propulsion model
- Algorithms from the U.S. Air Force jet engine cost model

The screenshot displays the NAFCOM software interface, which is organized into several sections for inputting engine parameters and design data.

- CER Methodology:** Includes radio buttons for 'L-RECH' and 'Conventional', and a 'Weight' field set to 0.0.
- System Test Hardware:** Features checkboxes for 'OTH Qty' (16), '% of Flight Unit' (114), 'D40', 'BTH', and 'Flight Unit'.
- Threshold:** A section for 'Pair (max 7) values of P1 and P2 to include'.
- Advanced Learning:** Includes fields for 'Learning %' (100), 'Production Qty' (1), and 'Make %' (70).
- Developmental Inputs:** A large section with multiple dropdown menus and checkboxes, including 'Design Process Improvement' (0.4 CAD, GFD, Limited Design Automation), 'Certification Approach' (0.5 Design Verification Specification (SSME)), 'Tooling Improvement Factor' (0.6 Modern (1992)), 'Test Process Improvement' (1.0 F-1, J-2, SSME (88)), 'Tooling Availability Factor' (1.0), 'Test Production Factor' (1.0), and 'Test Frequency/Min' (10, Range 10-50).
- Production Inputs:** Includes dropdown menus for 'Mfg Automation Level' (Fully Automated), 'Mfg Process Maturity' (New/Immature Process), 'Design Maturity' (New Design), 'Design Process' (Normal Experience, have completed similar type designs), 'Engine Cycle' (SC, Dual Preburner), 'Propellant Type' (LOX/H2), 'Chamber Pressure' (3300 psia), 'Reusability' (Reusable), 'Productivity Factor' (1.0 No Improvement (F)), and 'Thrust' (470 Klbs).



NAFCOM Features

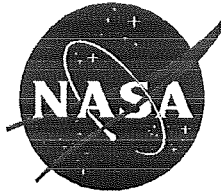


- ◆ Integration into collaborative environments
 - NAFCOM estimates are saved as Excel spreadsheets allowing easy manipulation of inputs external to the application

Elements	Weight	STHQty	FUPer	ManfMgmt	EngMgmt	NewDesign
Single Stage to Orbit Vehicle	346600					
Stage	346600					
SSTO Subsystems	346600					
Structures & Mechanisms	188000	1	130	50	70	100
Vehicle Structures & Mechanisms	123000	1	130	50	70	100
Tank Structures & Mechanisms	65000	1	130	60	50	100
Thermal Control	49000	1	130	50	70	100
Environment/Active Thermal Control	5500	1	130	50	50	100
Induced Thermal Protection	41000	1	130	50	70	100
Tank Thermal Control	2500	1	130	60	50	100
Reaction Control Subsystem	7000	1	130	50	70	100
Orbital Maneuvering System	4500	1	130	50	70	100
Main Propulsion System (less engines)	41000	1	130	50	70	100
Electrical Power and Distribution	32000	1	130	50	70	100
Command, Control & Data Handling	3500	1	130	50	70	100
Guidance, Navigation and Control	500	1	130	50	70	100
Environmental Control and Life Support	6000	1	130	50	70	100
Crew Accommodations	1100	1	130	50	70	100
Landing System	14000	1	130	50	70	100

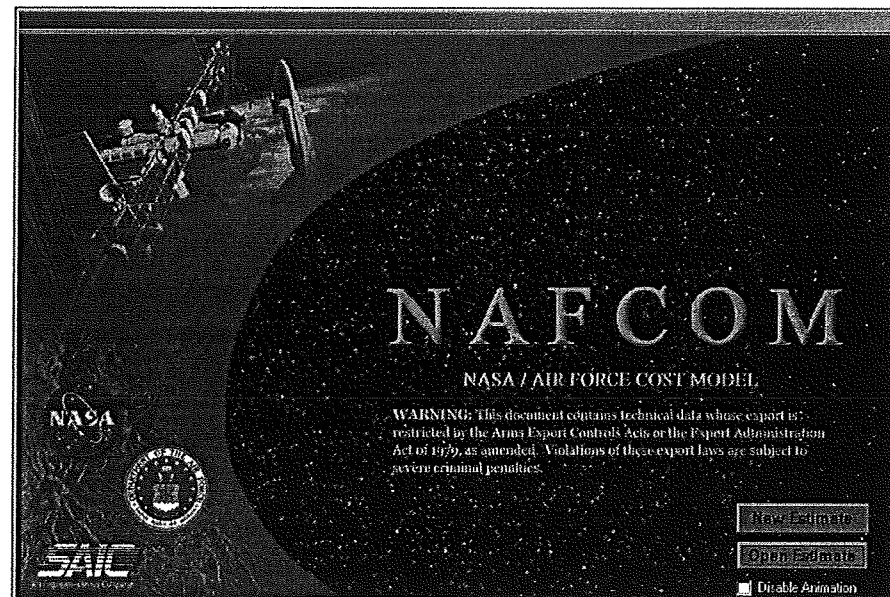


NAFCOM Sample Screens



Introduction Screen

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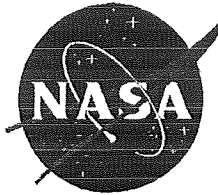


Wizard

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- ◆ A SINGLE screen dynamically changes based on Mission and Vehicle Type providing the capability to estimate hundreds of possible vehicle configurations
- ◆ Vehicle Types
 - Single-stage to Orbit
 - Two-stage to Orbit
 - Two-stage Bimese
 - Three-stage to Orbit
 - Four-stage to Orbit
 - Shuttle-derived

The screenshot shows the 'NAFCON' Wizard window. At the top, 'Select a Mission Type' is set to 'Unmanned Launch Vehicle' and 'Select a Vehicle Type' is set to 'Four Stage'. The interface is divided into four stages, each with a dropdown menu set to 'Expendable' and a 'Vehicle Engine Types' section with checkboxes for 'Liquid Rocket Engine', 'Combined Cycle Propulsion', 'Solid Rocket Motor', and 'Turbojet'. Stage 1 also includes a 'CTV' section with 'Cargo Only' selected and 'Expendable' checked. Stage 2 has an 'Engine Types' section with 'Liquid Rocket Engine' checked. Stage 3 has an 'Upper Stage' section with 'No engine' selected. Stage 4 has an 'Engine Types' section with 'Liquid Rocket Engine' and 'Solid Rocket Motor' both checked. A 'Continue' button is at the bottom right.



New Interface

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- ◆ Toolbar provides easy access
- ◆ WBS is generated based on wizard but allows addition of lower level elements
- ◆ Data and reports on screen change based on WBS element selected
- ◆ Various on-screen reports are provided
- ◆ Major cost drivers allow quick changes to template defaults on simple screens
- ◆ Funding profiles can be selected at the subsystem level
- ◆ Status bar provides dynamic view of cost estimate

The screenshot displays the NAFCOM software interface. On the left is a vertical toolbar with icons for Main View, Edit View, Database, Cost, Globals, Process Based, Trades, Time Phasing, and Cost Sheets. The main window is divided into several panes:

- Elements:** A hierarchical tree view showing the structure of a 'Four-Stage Vehicle'. It includes 'Stage 1 Subsystems' (Structures & Mechanisms, Thermal Control, Main Propulsion System, etc.), 'Stage 1 System Integration', and 'Program Management (PM)'.
- Weight:** A section with input fields for weight in lbs (49000.0) and kgs (22226.4).
- Cost Data:** A section showing 'Manufacturing Management' (60), 'Engineering Management' (50), and 'Naval Design' (100). Below this are 'DDT&E Cost' (2,093.7), 'Production Cost' (640.9), 'Flight Unit Cost' (640.9), and 'Total Cost' (2,734.6).
- Data View:** A table with columns: Mission, Sel., WBS Item, Weight, Launch Year, Known Identifiers, Subsystem Type, Level, and NASA.

The 'Data View' table contains the following data:

Mission	Sel.	WBS Item	Weight	Launch Year	Known Identifiers	Subsystem Type	Level	NASA
External Tank	<input checked="" type="checkbox"/>	Structural/Mechanical Group	62993.0	1981		Structural/Mechanical	Group	
Centaur-D	<input type="checkbox"/>	Structural/Mechanical Group	5732.0	1966	Structures basic construction is like Atlas. 80% of Atlas tooling was used to construct the tank.	Structural/Mechanical	Group	
IUS	<input type="checkbox"/>	Structural/Mechanical Group	1422.0	1982	Except for AT Skirt, Primary Structure is identical to DoD/IUS.	Structural/Mechanical	Group	
S-IC	<input type="checkbox"/>	Structural/Mechanical Group	150420.0	1968		Structural/Mechanical	Group	
S-II	<input type="checkbox"/>	Structural/Mechanical Group	55684.0	1968		Structural/Mechanical	Group	
S-IVB	<input type="checkbox"/>	Structural/Mechanical Group	19023.5	1968		Structural/Mechanical	Group	
SRB	<input type="checkbox"/>	Structural/Mechanical Group	26066.5	1981		Structural/Mechanical	Group	

At the bottom of the interface is a status bar with the following information: Total DDT&E: 14,785.7, Total Flight Unit: 3,517.7, Total Production: 3,517.7, Vehicle Total: 18,284.5, Total Weight (Est): 233,150.0, and 4/8/2002.



Detailed Input Screen

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- ◆ Detailed Inputs will include all non-global inputs available for a WBS element on one screen.
- ◆ The analogous missions can be changed below.

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File View Help About

Elements

Two-Stage Vehicle

Stage 1

Stage 1 Subsystems

- Structures & Mechanisms
 - Vehicle Structures & Mechanisms
 - Tank Structures & Mechanisms
- Thermal Control
 - Environment/Active Thermal Control
 - Induced Thermal Protection
 - Tank Thermal Control
- Main Propulsion System (less engines)
- Thrust Vector Control
- Electrical Power and Distribution
- Command, Control & Data Handling
- Solid Rocket Motor
- Liquid Rocket Engine
- Combined Cycle Propulsion Engine

Stage 1 System Integration

- Integration, Assembly and Checkout (IACO)
- System Test Operations (STO)
- Ground Support Equipment (GSE)

DataView

Mission	Del.	WBS Item	Weight	Launch Year	
External Tank	<input checked="" type="checkbox"/>	Structural/Mechanical Group	62993.0	1981	
Centaur-D	<input type="checkbox"/>	Structural/Mechanical Group	5732.0	1986	Structures b
IUS	<input type="checkbox"/>	Structural/Mechanical Group	1422.0	1982	Except for f
S-IC	<input type="checkbox"/>	Structural/Mechanical Group	150420.0	1968	
S-II	<input type="checkbox"/>	Structural/Mechanical Group	55684.0	1968	
S-IVB	<input type="checkbox"/>	Structural/Mechanical Group	19023.5	1968	
SRB	<input type="checkbox"/>	Structural/Mechanical Group	20066.5	1981	

Weight

49000.0 62993.0 kg

42226.8 28573.6 kg

System Test Hardware

STH Qty 1

% of Flight Unit 130

Throughput

Enter number as 7.1 values in FY 1000 is unitless

☐ DAO

☐ STH

☐ Flight Unit

Advanced Learning

Learning % 100

QMSA 1

Make % 70

Conventional CER Complexity Factors

DAO Complexity 1

DAO Integration 1

DAO Simplicity 1

Structural Efficiency

96 96 %

Manufacturing Management 60 60

Engineering Management 50 50

New Design 100 100

Deployed (1) No Deployed Structure 1

Funding Availability (2) Some Infrequent Delays Possible 2

Risk Management (3) Low Risk With Qualification at Component Level 3

Integration Complexity (2) Moderate Major Interfaces Involving Multiple Contractors/Centers 2

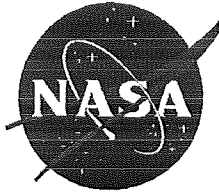
Pre-Development Study (2) One Study Contract - Between 9 and 18 Months of Study 2

816.6 287.2 220.9 220.9

DAO Cost STH Cost Flight Unit Cost Production Cost

Inputs CER Methodology

Total DOTE 40,588.3 Total Flight Unit 2,324.7 Total Production 2,304.7 Vehicle Total 42,890.7 Total Weight (lbs) 3,514,850.0 3/12/2002



Detailed Input Screen

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- ◆ Estimating Method will determine whether Complexity Generators or Conventional CERs are used.
- ◆ Mission Type, Data Level, and Element Type will determine what part of the database is available.
- ◆ Database Filters will change based on the Mission, Level, and Element selected. The database screen will change as filters are entered.
- ◆ Detailed Technical Descriptions will be provided for the selected item in the database.

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File View Help About

Elements

Two-Stage Vehicle

Stage 1

Stage 1 Subsystems

- Structures & Mechanisms
 - Vehicle Structures & Mechanisms
 - Tank Structures & Mechanisms
- Thermal Control
 - Environment/Active Thermal Control
 - Induced Thermal Protection
 - Tank Thermal Control
- Main Propulsion System (less engines)
- Thrust Vector Control
- Electrical Power and Distribution
- Command, Control & Data Handling
- Solid Rocket Motor
- Liquid Rocket Engine
- Combined Cycle Propulsion Engine

Stage 1 System Integration

- Integration, Assembly and Checkout (IACO)
- System Test Operations (STO)
- Ground Support Equipment (GSE)

DataView

Mission	SEL	Δ	WBS Item	Weight	Launch Year	
External Tank	<input checked="" type="checkbox"/>		Structural/Mechanical Group	62993.0	1981	
Centaur-D	<input type="checkbox"/>		Structural/Mechanical Group	5732.0	1986	Structures b
IJS	<input type="checkbox"/>		Structural/Mechanical Group	1422.0	1982	Except for
S-IC	<input type="checkbox"/>		Structural/Mechanical Group	150420.0	1968	
S-II	<input type="checkbox"/>		Structural/Mechanical Group	55684.0	1968	
S-IVB	<input type="checkbox"/>		Structural/Mechanical Group	19023.5	1968	
SRB	<input type="checkbox"/>		Structural/Mechanical Group	26066.5	1981	

7 Records Returned

Estimating Method

Complexity Generator

☒ Specific Analogy

☐ DE Average

Type

Shuttle Calibrated

Conventional CER

☐ Specific Analogy

☐ DE Average

Mission Type

Launch Vehicle Stages

Data Level

Element Type

Structures

COST (\$1M)

DDO

From To

Flight Unit

From To

SIZE (Weight)

From To

LAUNCH YEAR

From To

STRUCTURAL EFFICIENCY %

From To

Structural efficiency is derived by dividing structural weight by launch weight and subtracting the result from one.

MATERIAL TYPE

☐ Magnesium ☐ Fiberglass ☐ Thermoplastic

☐ Aluminum ☐ Boron ☐ Kevlar

☐ Titanium ☐ Steel ☐ Kapton

☐ Graphite ☐ Foam ☐ Fused Silica

☐ Beryllium ☐ Nylon ☐ Viton Rubber

☐ Carbon ☐ Abrasives ☐ Teflon

DEPLOYABLES

Number of Deployables

From To

Type of Deployables

☐ Solar Array Panels ☐ Small Antennas

☐ Booms ☐ Landing Gear

☐ Parabolic Reflector ☐ Door

Detailed Technical Descriptions

STRUCTURAL/MECHANICAL GROUP

The External Tank (ET) Structural is three components in one: a forward liquid oxygen tank, an intertank

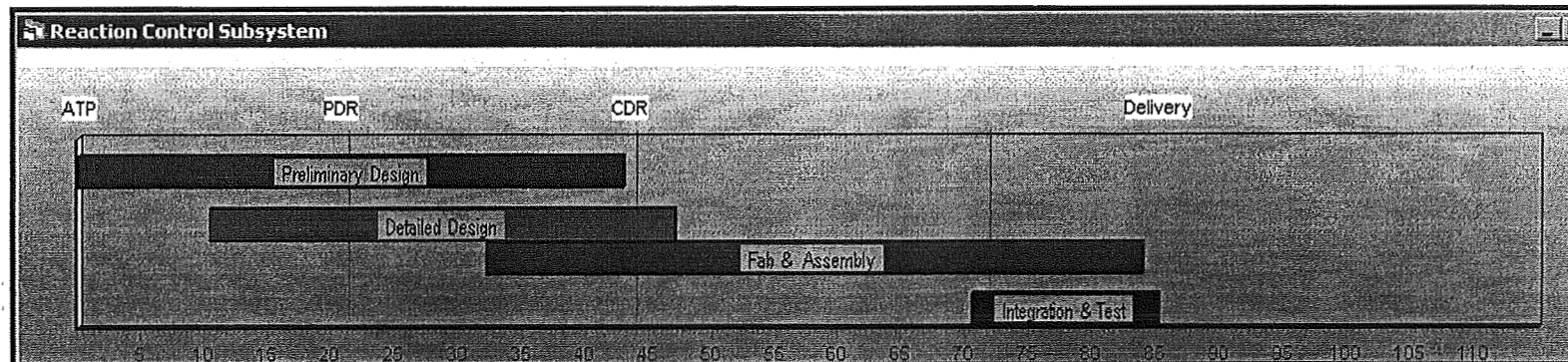
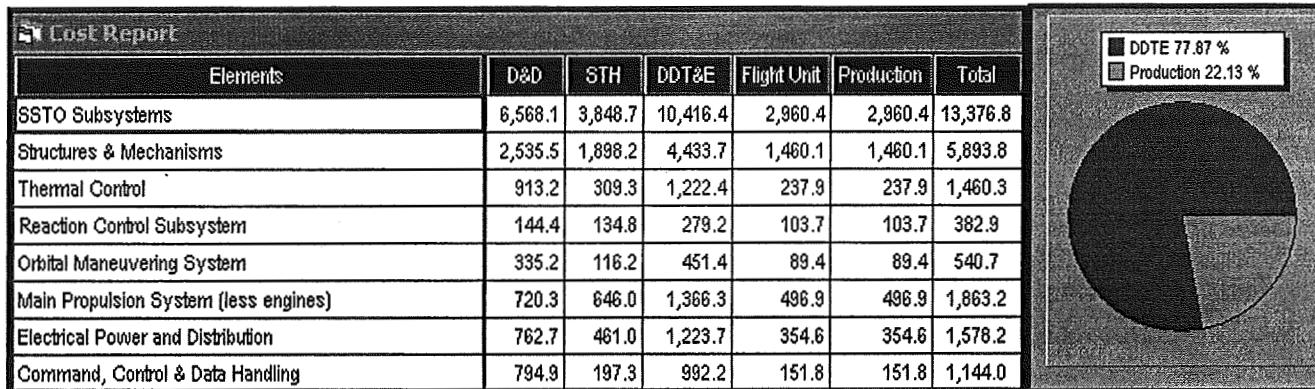
Clear Fields Help Select All Deselect All

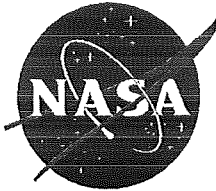
Inputs CER Methodology

Total DDO: 40,586.3 Total Flight Unit: 2,304.7 Total Production: 2,304.7 Vehicle Total: 42,980.7 Total Weight (lbs): 1,514,850.0 3/12/2002



Sample On-screen Outputs





Planned Release and Training



- ◆ Public release of NAFCOM is not planned
- ◆ Requests for NAFCOM will be controlled through NASA software usage agreement
- ◆ Launch Vehicle version was released in April 2002
- ◆ Unmanned Spacecraft version is planned for release this June
- ◆ Training will be completely revamped
 - Class time will be reduced to one day
 - Emphasis will be on model usage not estimating theory
 - Training will be scheduled beginning in early Summer
 - Training will be conducted using the unmanned spacecraft version of NAFCOM